Design Of Monopole Antenna With U Slot In Patch And Ground Plane Ideally Suited For Wireless Applications

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ABSTRACT- In this paper, a Monopole Antenna, square in shape, has been designed by cutting slots in both ground plane and patch for better impedance matching. The patch is assigned PEC material, and the substrate of the proposed antenna is Rogers RO3003(tm) having relative permittivity 3, and di-electric loss tangent of 0.0013. It is a Tri-band antenna having three resonant frequencies viz. 3.1GHz, 5.1GHz and 8.7GHz respectively, which exhibits same operating characteristics over a wider range of pass band. Comprehensive study of the frequency domain characteristics of the Antenna is being done, and is presented in this paper. The Antenna is simple and small in size, and is simulated using High Frequency Structure Simulator(HFSS) software. It is found to be suitable especially for Wireless Applications.

KEYWORDS- Monopole Antenna, Slotted Patch Antenna, Tri-Band Patch Antenna, U-shape Slotted Antenna, Inverted U-shape Slot, Square Monopole Antenna

I. INTRODUCTION

With the advancement in technology, designers are more often leaned towards designing newer technologies that can have a wider range of operation, but will be having a less complex structure. Antennas are being used in communication between systems, radar systems, microwave high resolution imaging and other data transmission systems having higher speed. A monopole antenna is a type of radio antenna in which the conductor is mounted over the ground plane perpendicularly, and is a resonant type of antenna whose length is specified by the wavelength of radio waves. In this paper, a patch antenna having three resonant frequencies has been presented, which consists of a U-Shape Slot both in patch and ground plane. The ground plane is being printed on the back side of the substrate parallel to the 50Ω feed line, and consists of inverted U-Slot which ultimately helps in better impedance matching and obtaining linear polarization and narrow vertical radiation pattern. The three resonant frequencies of 3.1Ghz, 5.1Ghz and 8.7Ghz bears good bandwidth and gain with S11<-10db.

In antenna design, the main issue that is to be considered is regarding the compact design of antenna that could cover the entire frequency band. Many antennas are being developed over the years, and experiments were already being carried out by putting different shape slots in the antenna for maximizing the impedance bandwidth and improving the gain of the antenna. The proposed antenna in this paper, consists of U-Shape slots that are mainly used for bandwidth enhancement and achieving multiple bands. U-Slots were first proposed by Lee and Huynh in the year 1995, and since then, experiments are being carried out, which has proven that these slots can provide dual and multi-band characteristics. The impedance bandwidth directly depends on the type of material being used on the substrate, and due to this, RO3003(tm) substrate having low di-electric constant was chosen. VWSR, Gain, Return loss and other important characteristics of the antenna are being studied, and presented in this paper. . U-Slots were first proposed by Lee and Huynh in the year 1995, and since then, experiments are being carried out, which has proven that these slots can provide dual and multi-band characteristics. The impedance bandwidth directly depends on the type of material being used on the substrate, and due to this, RO3003(tm) substrate having low di-electric constant was chosen. VWSR, Gain, Return loss and other important characteristics of the antenna are being studied.

Note: The monopole antenna was invented in 1895 by radio pioneer Guglielmo Marconi, for this reason it is sometimes called a Marconi antenna. Common types of monopole antenna are the whip, rubber ducky, helical, random wire, umbrella, inverted-L and T-antenna, inverted-F, mast radiator, and ground plane antennas

II. ANTENNA DESIGN

The Proposed Monopole antenna is shown below in various figures, and it consists of a substrate which consists of Rogers RO3003(tm) material with relative permittivity 3, di-electric loss tangent 0.0013 and Lande G factor 2. The width of the microstrip feed line has been made as 2mm(W5), and length is 7mm(L4), which is used to feed the antenna in order to transmit and receive radio frequency waves. The basic structure of the antenna consist of a patch in which a U-Shaped slot is being cut, and a ground plane that is located on the back side of the substrate exactly parallel to the feed line. The substrate width is 12mm(Ws), and length is 18mm(Ls), and the ground plane dimension are 12mm and 3mm respectively. The U-shape slot in the ground plane behaves as a resonant radiator, and the impedance of the slot(Z_s) is related with the complementary dipole antenna(Z_d) by the relation: [Z_d x Z_s= $\eta^2/4$], where ' η ' is the intrinsic impedance of free space.

The slot helps in matching the patch with the feed line for a wider range of frequencies by producing resistive input impedance, and also determines the radiation pattern distribution of the proposed antenna. The width of the three rectangle shaped slots that are being cut in order to form the U-shape slot in the patch are 0.7mm(W1 & W2) and 0.4mm(W3 & W4), and lengths of the three blocks are 8.2mm(L1 & L2) and 6mm(L3).

Current paths(Surface current) of three resonant frequencies are formed due to the slot in the ground plane, which induces three resonant modes and improves the capacitance between ground plane and the patch. Bandwidth and gain enhancement is also achieved, and the optimal dimension of the designed antenna is taken by performing parametric study. Fig.1 below shows the geometrical description of the proposed antenna.

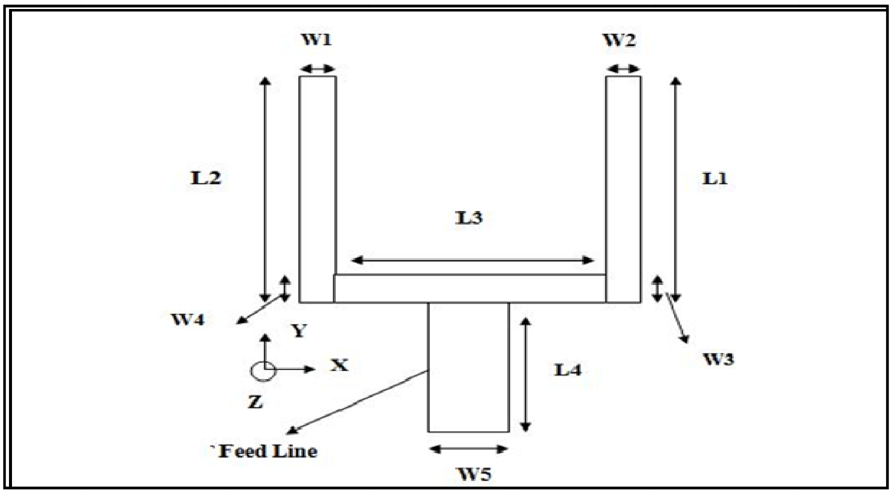

Fig. 1. Patch(U-Shape) Dimensions Of The Proposed Antenna

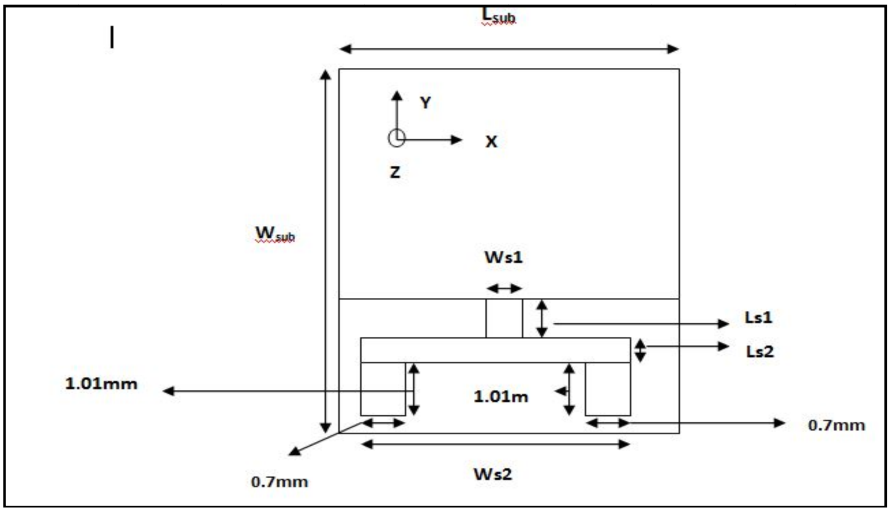

Fig. 2. Geometry Of The Ground Plane(With U-Slot)[Back View]

Specifications Of The Proposed Antenna are illustrated below:

L_{sub}= 18mm, W_{sub}= 12mm, W_{gnd}= 12mm, L_{gnd}=3mm, Ls1= 1.2mm, Ws1= 1.2mm, Ls2= 0.7mm, Ws2= 6mm, L1= 8.2mm, L2= 8.2mm, L3= 6mm, L4= 7mm, W1= 0.7mm, W2= 0.7mm, W3= 0.4mm, W4= 0.4mm.

Note: The dimensions of the proposed antenna were being found out by parametric study.

The side view of the proposed Microstrip Patch Antenna depicting the placement of ground plane and patch is illustrated below in Fig. 3.

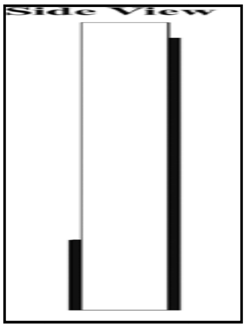

Fig. 3. Side View Illustration Of The Proposed Antenna

Considering the dimensions mentioned in Fig. 1 & Fig. 2, the proposed antenna is being designed in HFSS Software, and simulated after applying correct port assignment(Wave port). Proper Air Box(Vacuum) was assigned, and the antenna simulation was being carried out after assigning all the design parameters correctly. The Simulated antenna is shown in "Fig. 4 & Fig. 5" below.

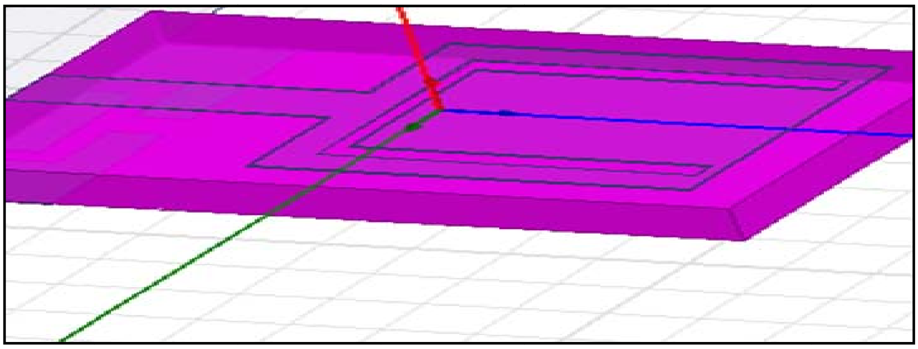

Fig. 4. Side View Of The Antenna(Simulated)

Inverted U-Shape Slot was introduced in the ground plane in order to obtain better impedance matching and bandwidth. The basic antenna structure consists of a square patch, a feed line, and a ground plane. The square patch has a width . The patch is connected to a feed line of width and length , as shown in Fig.1. Bandwidth and gain enhancement is also achieved, and the optimal dimension of the designed antenna is taken by performing parametric study.

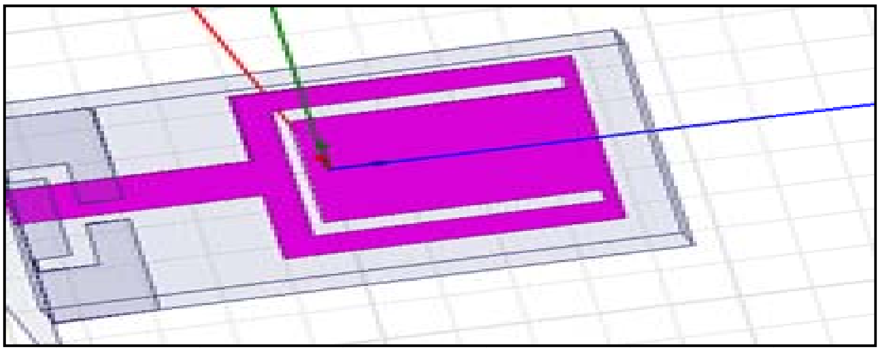

Fig. 5. Top View Of The Antenna(Simulated)

Fig. 4 and Fig. 5 depicts the Side and Top View of the antenna simulated in HFSS Software. The feed-gap distance, the sizes of U-shaped notch, and the sizes of two rectangular slots in the antenna's patch to obtain the wide bandwidth have been optimized by parametric analysis.

III. OBSERVATIONS AND RESULTS

A. Observations

From Return Loss Curve:

- **Resonant Frequencies Obtained:**
  - F1(In GHz)= 3.10GHz, F2(In GHz)= 5.10GHz, F3(In GHz)= 8.7GHz
- **S_{11}(In db) [Return Loss Or Reflection Co-Efficient]:**
  - S_{11}(F1)= -38.22db, S_{11}(F2)= -20.69db, S_{11}(F3)= -37.61db
- **Bandwidth(B.W)[In GHz]:**

    - B.W(F1)= 0.89GHz, B.W(F2)= 0.83GHz, B.W(F3)= 3.10GHz.
- **Gain(G)[In db]:**
    - G(F1)= 8db, G(F2)= 6.20db, G(F3)= 3.25db
- **Radiation Efficiency:** 2.46

Important Note: The solution frequency is fixed at 2.45GHz for all the cases.

B. Results

- *Return Loss:*

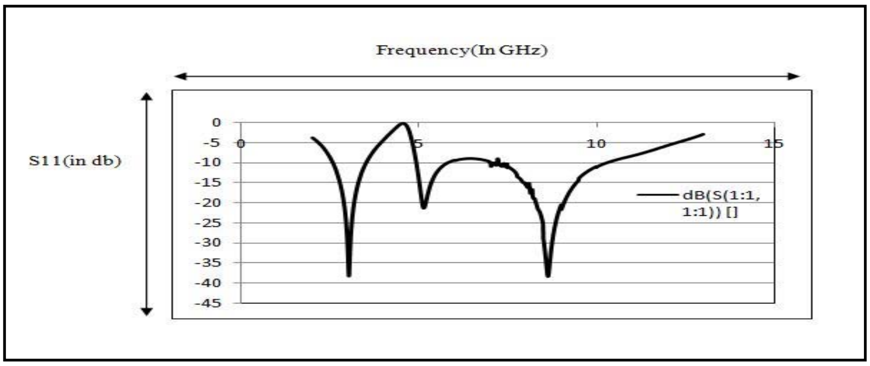

Fig. 6. Return Loss Of The Proposed Antenna

The return loss graph is shown in Fig. 6. The three resonant frequencies here are 3.1GHz, 5.1GHz and 8.7GHz respectively. The bandwidth in case of first and second resonant frequency is higher, and Gain is higher at two resonant frequencies viz. F2= 5.10GHz and F3=8.7GHz.

- *VSWR Graph:*

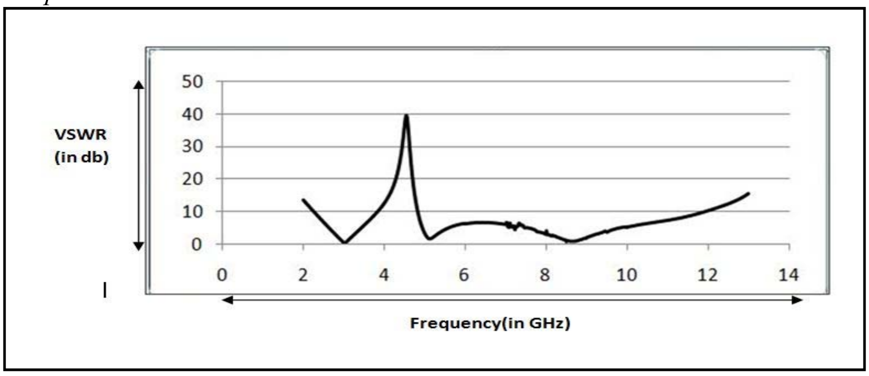

Fig. 7. VSWR of Antenna(U-Shape Slot In The Ground)

The Voltage standing wave ratio(VSWR) of the proposed antenna is shown in Fig. 7. VSWR signifies how well the antenna is matched with the transmisssion line. It can be seen that highest value of VSWR is obtained at a frequency of 4.5GHz(40db), and the lowest value of the same is obtained at a frequency of 8.4GHz.

- *Y-ParameterY(1,1) vs. Frequency Curve:*

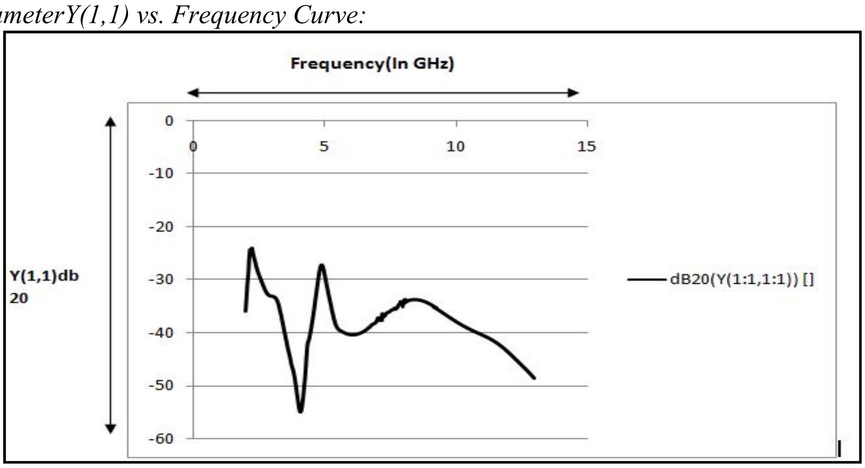

Fig. 8. Y(1,1) vs. Frequency Curve Of The Proposed Antenna

Fig. 8 shows the Y parameter vs. Frequency curve of the proposed monopole antenna. The Y-parameter, also called as the admittance is the complex ratio between a current and a voltage. A Y-parameter matrix mainly describes the behaviour of any linear electrical network that is generally regarded as a black box consisting of a number of ports. It can be seen that the highest value of VSWR is obtained at a frequency of 4.12GHz(-54.707db).

- *Radiation Pattern:*

Radiation pattern of an antenna defines the variation of the total power that is radiated by the antenna as a function of the direction away from the antenna. The power variation as a function of the arrival angle of the antenna is being observed in antenna's near field. Principal Plane patterns can be obtained by making two slices through the 3D pattern through the maximum value of the pattern or by direct measurement.

In general, radiation pattern refers to the directional dependence of the strength of radio waves from source or the antenna. The E-plane Antenna pattern resembles phi= 0 degrees, and H-Plane radiation pattern resembles phi=90 degrees. Both E-plane and H-Plane radiation pattern is shown in Fig.9(a) and 9(b) below.

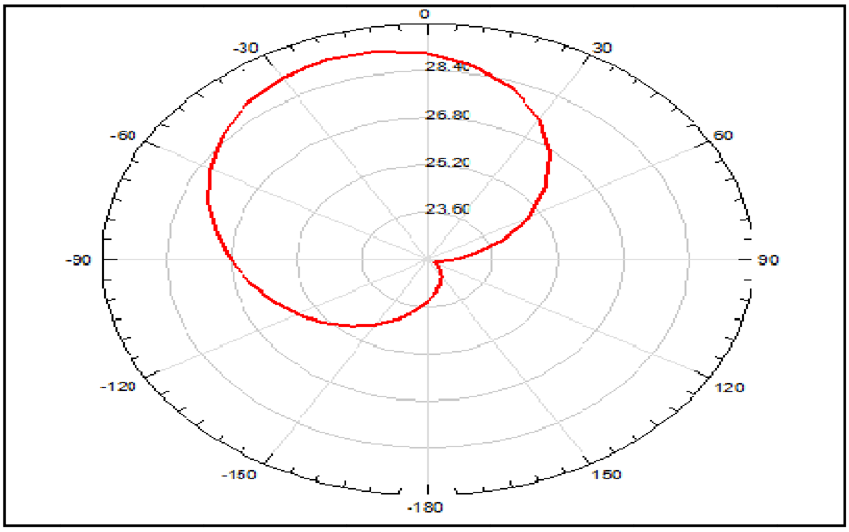

Fig. 9(a). E-Plane Radiation Pattern

The electric field or "E" plane determines the polarization or orientation of the radio wave. The E-plane radiation pattern is aligned in one direction, and is also referred to as Vertical radiation orientation. Fig. 9(a) shows the radiation pattern of the proposed antenna at 2.45GHz.

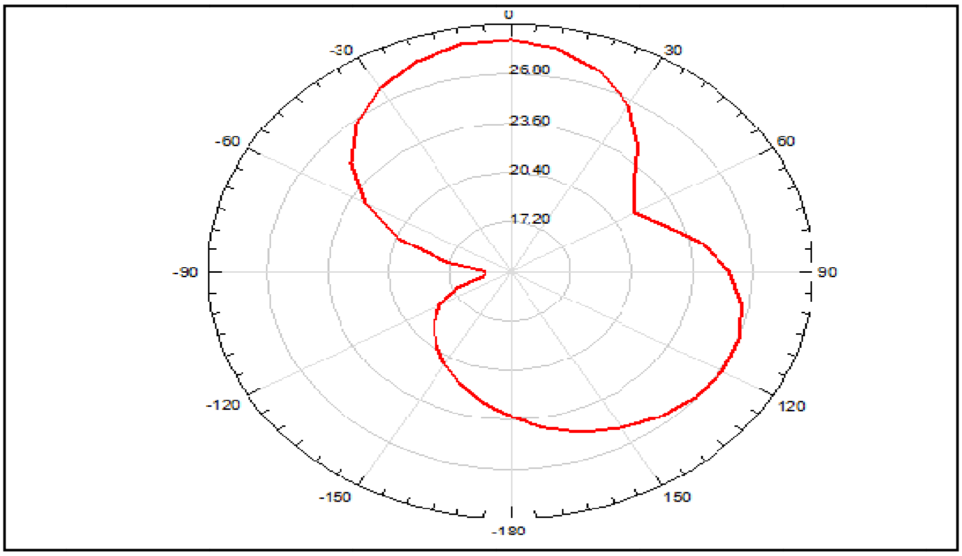

Fig. 9(b). H-Plane Radiation Pattern

The H-Plane radiation pattern looks like a dumbbell shape structure(bi-directional pattern) since the feed-line patch junction allow the alternating current to enter the antenna and leaves the antenna through the radiating edge of the patch and hence forming a magnetic field pattern having field maxima at the radiating edges in the direction of radiation and field minima at the centre of the patch. The H plane in this scenario will be orthogonal to dipole antenna (i,e XZ) and the polar pattern will be O shaped. Fig. 9(b) shows the H-Plane radiation pattern of the proposed antenna at 2.45GHz.

The radiation pattern of the proposed antenna is shown in "Fig. 9(a, b and c)". Nearly Omni-directional radiation pattern is achieved in Fig. 9(b) and fig. 9(c). The Radiation Pattern is shown for frequency of 2.45GHz.

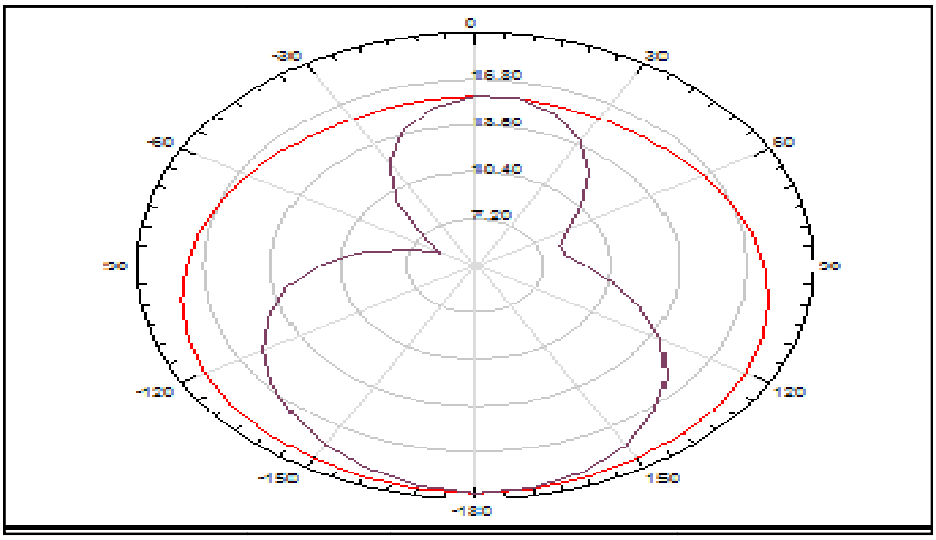

Fig. 9(c). Radiation Pattern(R_{total}) Of Antenna(At 2.45GHz)

Fig. 9(c) shows the radiation pattern of the proposed antenna simulated at 2.45GHz. Nearly Omni-directional pattern is achieved here. Good radiation behaviour is exhibited within the wireless applications frequency range.

- *3d Polar Plot:*

The 3d polar plot of the proposed antenna is shown in "Fig. 10" below. The pattern is almost getting equal to Omni-directional pattern in the middle portion.

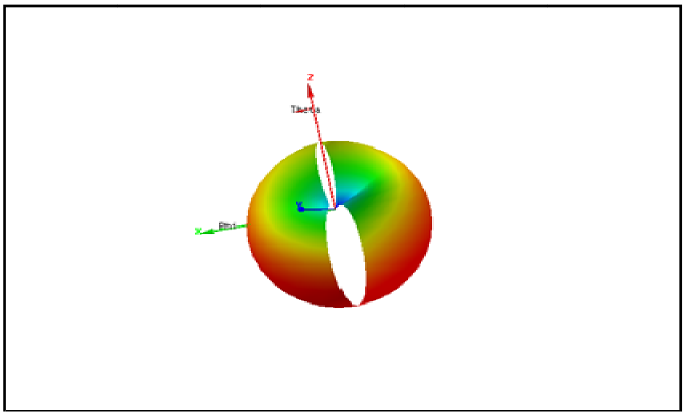

Fig. 10. 3d Polar Plot(U-Shape Slot In The Ground Plane)

Note: Electric field lines from one end of the antenna to the other follow the E-plane while magnetic field lines circulating around the antenna follow the H plane.

IV. CONCLUSION

A triple band small and simple Monopole Antenna has been demonstrated in this paper. The proposed antenna operates in three discrete frequencies viz. 3.1GHz, 5.1GHz and 8.7GHz respectively. Good Antenna performance in terms of Gain, Bandwidth and Radiation efficiency has been obtained within the acceptable limit of operation of wideband antennas. Slots used in Patch and ground plane of the antenna not only enhances impedance matching, but also reduces the size of the antenna to a greater extent. The complete study of the antenna is presented in this paper, and numerical study of the antenna is then being carried out in order to analyze the antenna in details. Bandwidth achieved in this case is quite high, and the antenna can preferably be used for various wireless applications.

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